U. S. DEPARTMENT OF ENERGY, OFFICE OF SCIENCE

ANNUAL CONTINUATION PROGRESS REPORT

1. DOE Award No.	2. Contractor No.	3. Date Prepared:	4. Task Term:
DE-SC0012704	2017-BNL-PO001-Budg	07-18-2016	Begin: Continuing End: Open

5. Title: BNL Medium Energy Group

6. Principal Investigator: Aschenauer, Elke-Caroline (631)-3444769

9. Nuclear Theory Program Manager:		
Gulshan Rai Office of Nuclear Physics SC-26 US Department of Energy 19901 Germantown Road Germantown, MD 20874-1290	12. Headquarters Organization: Office of Science 13. Program Office: Germantown, MD 14. Contractor Name: BROOKHAVEN SCIENCE ASSOCIATES BROOKHAVEN NATIONAL LABORATORY	

18. Project Description:

The focus of the BNL medium energy group is the polarized proton-proton and proton + nucleus program of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. RHIC delivers polarized p+p (p+A) collisions at center-of-mass energies of up to 510 GeV. This unique environment provides opportunities to study the polarized quark and gluon spin structure of the proton and QCD dynamics at a high energy scale and is therefore complementary to existing semi-inclusive deep inelastic scattering (SIDIS) experiments. Recent data from RHIC have for the first time shown a non-zero contribution of the gluons (Dg(x)) to the proton spin. The results of parity violating single spin asymmetries in W-boson production from 2012 have demonstrated that the RHIC W program will lead to a substantial improvement in the understanding of the light sea quark polarizations in the nucleon. The results based on the 2013 data will be released for the Spin conference in 2016.

In recent years, transverse spin phenomena have gained attention as they offer the unique opportunity to expand our current one-dimensional picture of the nucleon by imaging the proton in both momentum and impact parameter space. At the same time we can further understand the basics of color interactions in QCD and how they manifest themselves in different processes. Results from PHENIX and STAR have shown that large transverse spin asymmetries for inclusive hadron production extend from fixed-target kinematics to the highest RHIC energies and surprisingly large p_T. Recent RHIC measurements provide the essential data to elucidate the dynamical mechanisms that produce these large asymmetries, and a crucial test of the predicted process-dependence of the TMDs. A recent summary of the achievements and future opportunities of the RHIC spin program can be found in arXiv:1602.03922. The BNL-ME group is involved in both the PHENIX and STAR experiments working on new instrumentation, analysis addressing several key aspects of longitudinal and transverse spin physics questions and developing new physics opportunities with polarized beams at RHIC. The group is leading all aspects of further developing and measuring polarization at RHIC. The group is also spearheading the efforts to define a physics program for a future electron ion collider (EIC), the design for a dedicated EIC detector as well as its integration into the machine design.

19. Principal Investigator:

07/18/2016

Signature(s) Date

Brookhaven National Laboratory Continuation Progress Reports
SUBFIELD: Medium Energy (ME)
1st of October 2015 till 30th of June 2016

CURRENT GROUP MEMBERS:

Laboratory Permanent Staff:
E.C. Aschenauer (Group Leader) (STAR, EIC, Polarimetry) , A. Bazilevsky (joint)(PHENIX), W. Guryn (joint) (STAR), A. Kiselev* (EIC), J.H. Lee (joint) (STAR), A. Ogawa (STAR), W. Schmidke (STAR, Polarimetry)

Term and Other Staff:
O. Eyser (tenure track) (STAR, Polarimetry), S. Fazio* (STAR, EIC)

Post-docs:
B. Page* (STAR, EIC), R. Petti* (PHENIX, EIC), G. Webb (STAR, Polarimetry)

Graduate Students:
X. Chu* (>January 2015) (EIC), D. Kalinkin (>August 2015) (STAR), Zhanwen Zhu* (April 2016, shared with Shandong University, China)
The group is also supervising a PhD student from Temple University and one from Iowa State University.

* these peoples salaries are not or only partially funded through DOE ME base funding, the other funding sources are: funding for generic EIC Detector R&D and BNL Program Development funds for EIC

PHYSICS BEING ADDRESSED/GOALS:

- Unravel the individual parton (quarks and gluons) contributions to the helicity structure of the nucleon (PHENIX and STAR)
- Understand the origin of the transverse spin phenomena measured for center-of-mass energies of 5 GeV to 500 GeV in pp (PHENIX and STAR)
- First worldwide measurements of polarized diffraction in p+p/p+A collisions
- Can we experimentally find evidence of a novel universal regime of non-linear QCD dynamics in nuclei? (STAR)
- Can a nucleus, serving as a color filter, provide novel insight into the propagation, attenuation and hadronization of colored quarks and gluons? (STAR)
- Develop the physics program for an electron ion collider (EIC)
- Develop a detector and IR concept for an EIC@BNL (eRHIC), which also integrates all auxiliary detectors from the beginning
- Continue to further develop polarization measurements and offline analysis to increase statistical precision and reduce systematic uncertainties (RHIC and EIC)

The members of the group have had leading positions or made leading contributions to these areas.

PHENIX:

Alexander Bazilevsky

1. PHENIX deputy spokesperson (since January 2016)
2. Trigger coordinator for PHENIX (since 2010).
3. Spin physics working group co-convener (March 2013 – February 2016).
4. Member of the PHENIX Speakers Bureau (June 2015 – February 2016)
5. Member of fsPHENIX development group (for Spin and Cold QCD measurements)
6. Member of the writing committee for "The RHIC Cold QCD Plan for 2017 to 2023"

Richard Petti

1. DC reconstruction software coordinator
2. Paper and Poster Selection Committee for the BNL Young Researcher Symposium 2015

STAR:

E.C. Aschenauer

1. chair of the writing committee for the RHIC Cold QCD Plan (arXiv: 1602.03922)
2. was 2014 to 2016 a member of the STAR Beam-use-request writing committee.
3. Member of 2 STAR GPCs
4. Co-PI for Physical Review Letters 116 (2016) 132301

O. Eyser

1. Member of the nuclear physics seminar committee (chair since 2014)
2. software coordinator for the FMS and detector expert for the FPS in STAR
3. Member of the STAR trigger-board 2015 and 2016
4. Chair of STAR GPC on IFF

S. Fazio

1. has in 2016 become a member of the STAR Beam-use-request writing committee.
2. Member of the STAR GPC on rho^0 in Au+Au, GPC ID: 222

W. Guryn

1. co-convener of the STAR UPC-pp2pp working group
2. project leader for the Roman Pot project at STAR
3. safety representative for the medium energy group

J.-H. Lee

1. Chair of the STAR Trigger board for 2015 and 2016
2. a member of the 2016 STAR Beam-use-request writing committee
3. GPC chair for STAR paper: Azimuthal transverse SSA

A. Ogawa

1. was/is since years a member of the STAR trigger board and has been its chair in 2013.
2. since 2014 a member of the STAR talks committee.
3. has been since years the trigger software coordinator and BBC detector expert
4. GPC chair for STAR paper: dijet A_{LL}
5. chair internal review for EPD

B. Page

1. is a co-convener of the STAR jet finding working group

B. Schmidke:

1. GPC chair for STAR paper: double spin asymmetry A_{NN} in elastic pp scattering

G. Webb

1. is a co-convener of the STAR jet finding working group

Polarimetry:

Bill Schmidke, Oleg Eyser and Grant Webb are the leading people for the RHIC online and offline polarization analysis.

eRHIC:

Elke-C. Aschenauer

1. co-chairs the BNL EIC-taskforce

Introduction:

A myriad of new techniques and technologies have made it possible to inaugurate the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory as the world's first high-energy polarized proton collider. RHIC delivers polarized proton-proton collisions at center-of-mass energies of up to 510 GeV. This unique environment provides opportunities to study the polarized quark and gluon spin structure of the proton and QCD dynamics at a high energy scale and is therefore complementary to existing semi-inclusive deep inelastic scattering (SIDIS) experiments. Recent data from RHIC have for the first time shown a non-zero contribution of the gluons ($\Delta g(x)$) to the proton spin. The results of parity violating single spin asymmetries in W-boson production from 2012 have demonstrated that the RHIC W program will lead to a substantial improvement in the understanding of the light sea quark polarizations in the nucleon.

In recent years, transverse spin phenomena have gained attention as they offer the unique opportunity to expand our current one-dimensional picture of the nucleon by imaging the proton in both momentum and impact parameter space. At the same time we can further understand the basics of color interactions in QCD and how they manifest themselves in different processes. Results from PHENIX and STAR have shown that large transverse spin asymmetries for inclusive hadron production extend from fixed-target kinematics to the highest RHIC energies and surprisingly large p_T. Future RHIC measurements will provide the essential data to elucidate the dynamical mechanisms that produce these large asymmetries, and crucial tests of the predicted process-dependence of the TMDs. A summary of the achievements and future opportunities of the RHIC spin program can be found in arXiv:1602.03922. With the fully reconstructed data from p+p and p+A collisions from run-2015 becoming available, new possibilities are opening up to study how initial and final state effects are modified in the nuclear medium. The BNL-ME group is involved in both the PHENIX and STAR experiments and in all aspects of measuring and further developing polarization measurements at RHIC. The group is also spearheading the efforts to define a physics program for a future electron ion collider (EIC), the design for an EIC detector fully optimized for DIS as well as its integration into the machine design.

Contribution to PHENIX:

The 2016 RHIC Run was focused on heavy ion measurements, which included d+Au energy scan, dedicated for flow and correlation measurements in small collision systems. Due to unfortunate problems with MPC-EX timing in Run 2015 making the MPC-EX data collected in 2015 unusable, we'll performed the cold nuclear matter related measurements with the MPC-EX from Run 2016 d+Au $\sqrt{s}$=200 GeV data. In this run we collected statistics similar to Run15 p+Au projection.

As a PHENIX Trigger coordinator A.Bazilevsky was responsible to define a set of triggers used for physics data taking during 2016 run. A usual set of rare triggers was setup to enhance our electron/photon/π^0/muon/di-muon samples, as well as central collision sample. The main challenge in 2016 run was d+Au collisions at low center of mass energies, $\sqrt{s}$=19.6 and 39 GeV, for which our traditional minimum bias trigger based on the BBC detectors was very inefficient, even for central collisions. For the first time, we setup and successfully used the FVTX-based trigger to tag d+Au collisions with high efficiency – nearly 100% for central collisions even at the lowest $\sqrt{s}$=19.6 GeV. This new trigger allowed PHENIX to efficiently sample d+Au data in 2016 run at all collision energies. The trigger-coordinator's responsibilities also included monitoring and tuning trigger performance during the run.

In FY2016 we have been also concentrating on the data analysis from previous years data, and continuing developing the physics case and detector design for the PHENIX longer term upgrades, focusing on the forward upgrade fsPHENIX and evolution to a DIS physics detector ePHENIX.

In the physics analyses described below, A.Bazilevsky either made leading or considerable contribution to the analysis, or contributed as a major reviewer or adviser (in his role as the PHENIX Spin physics working group convener).

Single helicity asymmetries of W bosons measured over an extended rapidity range enable us to distinguish the flavor separated sea quark polarization from valence quarks. PHENIX measures W-bosons via their weak leptonic decays, identifying electrons/positrons in the PHENIX central arms or muons in the forward arms. The 2009 results of W->e decays in the PHENIX central arms were published in 2011. Results from 2011-13 have been finalized, and the corresponding paper published in Phys.Rev. D 93, 051103(R) (2016). W->mu results from PHENIX Muon Arms from 2011-13 were "preliminary" approved in previous years; the corresponding publication is in preparation (after refining cuts to improve the signal to background ratio utilizing the FVTX, the Forward Silicon Vertex Tracker, fully operational in 2013).

Double helicity asymmetries have been a powerful tool to constrain the gluon polarization in the proton. Measurements at $\sqrt{s}$ = 500 GeV and at large rapidity extend the range of probed gluon momentum fraction to smaller values of the parton momentum fraction, x. These measurements require large integrated luminosities. The relative luminosity between different polarization states has emerged as one of the major systematic uncertainties. Relative luminosity uncertainties have been significantly decreased recently in PHENIX, particularly for the $\sqrt{s}$ = 510 GeV data samples. The paper on the double helicity spin asymmetry, A_{LL}, for inclusive π^0 and η-meson from Run9 $\sqrt{s}$=200 GeV has recently been published in Phys. Rev. D 90, 012007 (2014). The π^0 cross-section and A_{LL} analysis from 2012-2013 at $\sqrt{s}$ = 510 GeV was finalized and published in Phys.Rev. D 93, 011501(R) (2016). For the first time we observed a non-zero A_{LL} in the inclusive hadron production, which confirmed the non-zero ΔG in the x-range probed in RHIC kinematics, earlier seen by STAR in the A_{LL} for inclusive jets and di-jets. Furthermore, these data are expected to extend the ΔG constraint to lower x, down to $x \sim 10^{-2}$. The cross section results were found in excellent agreement with the NLO pQCD theory calculation, which utilized parton-to-pion fragmentation functions (FF) from the recent DSS14 global analysis, which prefer a smaller gluon to pion FF. Charged pion cross section and A_{LL} results from the 2009 $\sqrt{s}$=200 GeV data were recently published in Phys. Rev. D91 (2015) 3, 032001. The analysis of charged pions from 2012-13 $\sqrt{s}$ = 510 GeV is ongoing and results are expected soon. The MPC π^0 (or cluster) double helicity asymmetry analysis from Run-11, 12 and 13 at $\sqrt{s}$=500 and 510 GeV is our particular focus since it provides access to the polarized gluon distribution at even lower x ($x \sim 10^{-3}$) currently unconstrained. The analysis of the A_{LL} measured with the MPC in the 2011-13 runs is ongoing, and the results are expected soon. In the meanwhile this analysis has demonstrated the possibility to improve the relative luminosity uncertainty to the level better than 10^{-4}, which is of crucial importance for extending the constraint on ΔG to lower x. Heavy flavor measurements at forward rapidity gives us another way to probe ΔG at lower x. J/Ψs measured in the PHENIX Muon arms at $\sqrt{s}$ = 510 GeV are produced predominantly via gluon-gluon fusion with one gluon in the x range ($0.03<x<0.3$) already probed with the RHIC π^0 and jet data, and with the other gluon at $0.001<x<0.004$. This also gives access to the yet unexplored low x region for ΔG. The analysis of the 2013 data at $\sqrt{s}$ = 510 GeV is finalized, and the paper has been recently submitted to Phys. Rev. D.

Recent investigations, both experimental and theoretical, have shown that separating initial and final state effects is crucial in our understanding of transverse spin effects. They can be separated measuring various probes sensitive to either initial or final state effects, or both. PHENIX has previously published transverse asymmetries of charged and neutral hadrons at mid-rapidity, and for J/ψs in the PHENIX muon arms. The paper for single muon A_N results is under preparation. During the 2015 RHIC Run we collected data from collisions of transversely polarized p+p, and for the first time p+Al and p+Au collisions. Run 2015 provided PHENIX with about a factor of three larger transverse spin p+p data set, compared to all previous years combined, which will allow improving our earlier results. An early analysis from Run15 p+p, p+Al and p+Au collisions has already revealed a very surprising results for the forward neutron A_N. We observed an unexpected 3-fold increase in the magnitude of the asymmetry and sign flip of the asymmetry going from pp to pAu. At this moment in time no theory can explain this observation. The results were PHENIX "preliminary" approved and brought to the attention of a few theoretical groups.

R.Petti has been the point of contact for issues and maintenance of the drift chamber reconstruction code. He has pursued an analysis of direct photons at low momentum in proton-proton collisions to obtain the baseline measurement to the important Au+Au direct photon measurement. R. Petti is also supervising a student to do the direct photon analysis for data sets at lower center-of-mass energies.

A.Bazilevsky continued contributing to the PHENIX longer-term upgrade programs, particularly fsPHENIX and ePHENIX. The main emphasis in FY2016 has been the implementation of the full GEANT4 simulation for fsPHENIX and ePHENIX and developing their design.

Contribution to STAR:

The focus of the group has both been to provide first analysis results from recent runs and to finalize mature analyses of older data sets for publication. The group made also major contributions to recent STAR detector upgrades.

Partonic Structure of the Proton

In the past, the RHIC experiments have mainly contributed to the knowledge of the gluon helicity structure through the measurement of polarization dependent asymmetries in the production of neutral pions and jets at a center-of-mass energy of 200 GeV. Recent global QCD analyses have shown that the truncated moment of the gluon helicity, $0.05<x<0.2$, is indeed not zero. This has led to a change in the functional form of the polarized gluon distribution and it points towards a significant contribution of the gluon to the proton spin. An increase in the center-of-mass energy as well as measuring correlations between particles (and jets) extends the total kinematic reach while at the same time limiting the covered range as function of the covered detector pseudorapidity.

Brian Page and Grant Webb have studied the cross sections of dijet production at $\sqrt{s}$ = 200 and 500 GeV in the run 9 data. The analyses also include the double helicity asymmetry, A_{LL}, and a publication of the results at 200 GeV is nearing completion (collaboration internal review under guidance of Akio Ogawa). The dijet analysis at 500 GeV is currently undergoing a thorough investigation of the underlying event (Grant Webb for run 9 and Dmitry Kalinkin for run 12) similar to the high energy measurements at the LHC. Dmitry Kalinkin has obtained existing code from De Florian and Vogelsang to calculate the NLO cross sections and asymmetries for dijets. The code has been modified for modern (un)polarized PDFs and results of the calculations will be included for comparison in the upcoming publications. Dmitry Kalinkin has also started to do impact studies of the different jet cross sections on unpolarized parton distributions. The RHIC kinematics have the advantage that they can constrain PDFs at high x --- a region where uncertainties especially for the gluon PDF are large and cause large uncertainties for high mass searches at the LHC.

The forward calorimetry at STAR (FMS, $2.5<\eta<4.0$) extends the sensitivity of the kinematic coverage to partonic momenta as low as $x\approx0.001$ through measurements of neutral pions at $\sqrt{s}$=500 GeV. The analysis of double helicity asymmetries from runs 12 and 13 is currently being finalized by Chris Dilks from Pennsylvania State University for publication. The observed asymmetries are on the order of 5×10^{-3} or less, which requires an excellent understanding of the relative luminosity between different beam helicities as the main source of systematic uncertainties.

The ratio of charged W-boson production, $\sigma(W^+)/\sigma(W^-)$, as function of rapidity is a golden observable to get information on the parton distributions of light sea quarks in the proton. A first measurement of this ratio has been done based on the inclusive electron technique that was used for the longitudinally polarized parity violating single spin asymmetry, A_L. Salvatore Fazio has also adapted the analysis procedure of fully reconstructed W-bosons which was used for transverse spin asymmetries in run 11 and included the run 12 data set. Preliminary results have been presented at conferences. As soon as Run-13 data are analyzed preparation of a paper will start.

Transverse Spin Phenomena

The STAR experiment has recently made some significant contributions to the field of transverse spin phenomena. Among them are the first data from 2015 that may address the diffractive nature of transverse single spin asymmetries, A_N, at forward rapidity and the possible suppression of those same asymmetries in proton-ion collisions compared to proton-proton collisions which can be related to gluon saturation at small-x. Recent results and future prospects have been summarized in the RHIC Cold QCD Plan for the years 2017-2023 (arxiv:1602.03922, writing committee chaired by Elke Aschenauer).

Based on the 2011 transversely polarized data at 500 GeV, a proof-of-principle analysis has been performed to fully reconstruct the $W \rightarrow e+\nu$ decay from the lepton and the recoil of the beam remnant in the STAR central barrel detector. This analysis also includes a first look at A_N in Z^0 production. The analysis has been finalized by Salvatore Fazio and is now published in Physical Review Letters 116 (2016) 132301. This measurement is the first experimental test of the non-universality of the transverse momentum dependent spin-orbit correlations in the proton (Sivers function), which is predicted from the process dependence and the color flow between the hard scattering and the proton remnant. While the results are statistically limited at this point, the results have posed as main motivation for the upcoming RHIC run in 2017. With an increase of about 16 in the integrated luminosity, this measurement will be a decisive test of the non-universality of the Sivers function and it will, at the same time, provide much needed input for the Q^2 evolution of transverse momentum dependent distribution functions. For the new data (and also for the 2013 data), the tracking algorithm has been improved which leads to an improved reconstruction efficiency and subsequently to an increase of about 25% more W-bosons (detailed studies by Salvatore Fazio and others under guidance from Elke Aschenauer).

STAR has also recently published first results of transverse asymmetries in dihadron correlations, which are the first direct evidence of the transversity distribution from proton-proton collisions and first observation of non-zero transverse spin asymmetries at midrapidity altogether (paper review under guidance of Oleg Eyser). Similar preliminary results have been obtained from hadron asymmetries in jets, where the transversity distribution couples with a spin-dependent fragmentation process. With the knowledge of the non-zero spin-dependent fragmentation in the STAR kinematics, the previous analysis techniques are being adapted by Oleg Eyser for unpolarized data at 200 and 500 GeV where parton spin-orbit correlations (Boer-Mulders function) can be extracted. The p_T-dependent results will also provide information about contributions from gluon radiation (Cahn effect).

Transverse single-spin asymmetries at forward rapidities have been observed at very sizable amplitudes and they are particularly interesting in many theoretical concepts. Before the 2015 RHIC run, the Forward Meson Spectrometer, FMS, has been refurbished and equipped with a preshower detector for the measurement of direct photons, which do not involve any final state fragmentation. Transverse asymmetries of direct photons address the non-universal character of the Sivers function through the twist-3 formalism in collinear QCD. The analysis has started after calibrations of FMS and preshower were ready for the data production/reconstruction (Oleg Eyser, Akio Ogawa). The preshower performance has been tested in light meson reconstruction (single pions as well as two-pion correlations, Akio Ogawa). A detailed study of J/Psi mesons is in progress and will be a first step of a measurement of J/Psi suppression, R_{pA}, in proton-ion collisions (Oleg Eyser). Chris Dilks has first looked at correlations of the Roman Pot detectors/triggers and transverse asymmetries of neutral pions in the FMS. A detailed analysis was awaiting for the alignment calibration of the Roman Pots and full production of the data, which is done by graduate students from Cracow under the leader ship of Wlodek Guryn.

For the upcoming RHIC run in 2017, the FMS-preshower setup up will be complemented by a postshower which has been proposed by Elke Aschenauer and others. This detector will allow to also measure A_N for Drell Yan. The simulations proofing that the combination of preshower, FMS and postshower can suppress the QCD background by a factor of 10^6 making a measurement of A_N for Drell Yan at all possible, The three prong approach of measuring A_N for DY, $W^{\pm}$, Z^0 and direct photons will make STAR the only experiment to constrain the QCD evolution of TMDs, the sea quark Sivers function and probing the sign change of the Sivers function between DIS and p+p collisions not only in the TMD formalism but also in the Twist-3 formalism. The new postshower detector will be very similar in design to the preshower and Akio Ogawa and Oleg Eyser have finalized the layout; the STAR engineers in the operations group are finalizing the design of the frame and support structure for installation and operation. Additional simulation studies are done by students/postdocs of newly affiliated university groups (Iowa State and UC Riverside) under guidance of the RHIC Medium energy group. They will also help with the construction of the detector in the laboratory before installation.

Transverse poalrized p+A physics

Until today the golden channel at RHIC to observe strong hints of saturation has been the angular dependence of two-particle correlations, because it is an essential tool for testing the underlying QCD dynamics. In forward-forward correlations facing the *p*(*d*) beam direction one selects a large-*x* parton in the p(d) interacting with a low-*x* parton in the nucleus. For $x < 0.01$ the low-*x* parton will be back-scattered in the direction of the large-*x* parton. Due to the abundance of gluons at small *x*, the backwards-scattered partons are dominantly gluons, while the large-*x* partons from the p(d) are dominantly quarks. The measurements of di-hadron correlations by STAR and PHENIX have been compared with theoretical expectations using the CGC framework based on a fixed saturation scale Q_s and considering valence quarks in the deuteron scattering off low-*x* gluons in the nucleus with impact parameter $b = 0$. Alternative calculations based on both initial and final state multiple scattering, which determine the strength of this transverse momentum imbalance, in which the suppression of the cross-section in d+Au collisions arises from cold nuclear matter energy loss and coherent power corrections have also been very successful to describe the data.

The 2015 p+Au run at RHIC has provided unique opportunities to study this channel in more detail at STAR. The high delivered integrated luminosities allow one to vary the trigger and associated particle p_T from low to high values and thus crossing the saturation boundary and reinstate the correlations for central p+A collisions for forward-forward π^0's.

Studying di-hadron correlations in p+A collisions instead of d+A collisions has a further advantage. In a paper by Strikmann and Vogelsang it was pointed out that the contributions from double-parton interactions to the cross-sections for d+A $\rightarrow \pi^0\pi^0X$ are not negligible. They find that such contributions become important at large forward rapidities, and especially in the case of d+A scattering. Whether or not this mechanism provides an alternative explanation of the suppression of the away-side peak in π^0-π^0 can be settled with the 2015 p+A data. Akio Ogawa is the main analyzer and will soon provide preliminary results for the 2015 p+Au data.

Diffractive Physics and Elastic Scattering

The main focus of the group is on the analysis of the high statistics data from proton-proton and proton-ion collisions in the 2015 RHIC run. Wlodek Guryn is coordinating the data analysis as a co-convener of the UPC Physics Working Group in STAR. Among the first tasks were the alignment calibration and detailed studies of the detector noise to determine the pedestal cuts. Wlodek Guryn worked on the alignment with one of the collaborators from Cracow (Bogdan Pawlik). The first set of corrections has been used to produce microDST files for analysis. In a second step, a time dependent set of corrections was obtained and is used in the run-by-run analysis. Wlodek Guryn is also working with a collaborator from Cracow (Bogdan Pawlik) on the analysis of elastic proton-proton scattering events. First results on elastic scattering were presented at the STAR Collaboration Regional Meeting in Cracow in June of 2016. Wlodek is also working with a PhD student from Cracow (Lukasz Fulek) on simulations of the proton transport using the full GEANT geometry information of the relevant detectors.

Wlodek Guryn also supervised an Engineering thesis of Ms. Magdalena Dobrowolska, Warsaw University of Technology, Warsaw, Poland, who defended her thesis in February 2016, with the overall grade A.

The goals for the coming year for the project are:

- The RP system in Run15 in p+p and p+Au collisions has performed as planned. The analysis of the data collected in Run 15 will continue. Systematic and continuous effort to ensure the optimal performance of the system to collect quality data sets has been made during and after the run.
- Finalize data reconstruction of the high statistics p+p and p+A data sample from Run15.
- Produce the first results and prepare for publication on cross-sections and dynamics of central exclusive process in p+p at $\sqrt{s}$=200 GeV. .
- The A_{NN} paper is still in the collaboration review.
- Develop the physics case and triggers, and prepare for high statistics data taking at $\sqrt{s}$=510 GeV in Run17. Two main subjects for the diffractive program with RPs at $\sqrt{s}$=510 GeV is extending CEP study in wider kinematic range and exclusive *J/ψ* photo-production for studying GPD *Eg*.

Ultra-Peripheral Collisions

One member of the Spin group (William Schmidke) is also active in the UPC physics program within the STAR collaboration. The goal is the study of photoproduction of vector mesons in heavy ion and polarized proton collisions. This is made possible because of the flux of Weizsaecker-Williams photons from the beam particles; the flux is very large from highly charged heavy ions. Of special interest is the production of charmonium J/Psi vector mesons. The charm quarks are produced through the photon-gluon fusion process, allowing access to the gluon content of the target nucleon or nucleus.

Work has continued on analysis of the Run10 and Run11 data for J/Psi photoproduction in Au+Au collisions. Preliminary results for the cross section as functions of rapidity and transverse momentum p_T were presented at the DIS 2016 workshop. The transverse momentum distribution shows a dominant component at low p_T, indicating coherent photoproduction off the entire Au nucleus. There is also a significant component at higher p_T, which is from photoproduction off individual nucleons. These results are being finalized, and await the addition of similar data from Run14 which is not yet finished processing; this will nearly double the size of the data sample, presently approximately 200 events. The trigger for these data was based on the STAR time-of-flight (TOF) system. In Run14, a trigger using the STAR barrel electromagnetic calorimeter (BEMC) was also implemented. Detecting the decay J/Psi->e^+e^-, it was able to operate with a lower prescale than the TOF based trigger and provided a larger sample of this process. If the processed data show that this trigger worked successfully, it will more than triple the size of the data sample. The final best sample of J/Psi production in AuAu collisions will then lead to a publication of these results.

In Run15, RHIC collided polarized protons with Au and Al nuclei. For the process of a photon emitted from the nucleus and undergoing photoproduction of J/Psi mesons off the polarized proton, the single spin asymmetry, A_{UT}, of this process is proportional to the generalized parton distribution E_g, which carries information on the gluonic orbital angular momentum contribution to the proton spin. STAR collected a sample of this process with the BEMC based trigger, in coincidence with a hit in the STAR Roman Pot system to measure the final state proton. These data await processing; when analyzed, it will be the first measurement sensitive to the gluon orbital angular momentum in the proton.

During the Au+Au period of Run16, the BEMC trigger was again used to collect J/Psi events. Owing to the low noise rate of the trigger, it was able to operate with looser selection criteria, sampling a cross section an order of magnitude larger than previous versions. From this, and the large luminosity delivered in Run16, the final sample of J/Psi production in Au+Au collisions will be 20-40 times larger than the present sample, allowing the most precise study of this this process. This trigger also was used during the 100x100 GeV and 31x31 GeV d+Au periods of Run16, and will provide a first look at J/Psi production with these beam species.

Contribution to RHIC Polarimetry:

There are four types of polarimeters, which are supported through the DOE RHIC operation funds.

1. Four fast proton-carbon (pC) polarimeters in RHIC giving relative polarization measurements and determining the polarization profile as well as the polarization lifetime through a fill;
2. An absolute polarimeter in RHIC using a polarized hydrogen jet target (H-jet);
3. Local polarimeters at the experiments to measure the effect of the spin rotators at the experiments;
4. A fast AGS polarimeter.

Our group is responsible for the silicon detectors and data analysis from both the H-jet (Oleg Eyser) and pC polarimeters (Bill Schmidke, Grant Webb); the group operates and maintains the pC polarimeters (Bill Schmidke) and data acquisition during the RHIC runs, and provides rapid results as input for RHIC operations.

Carbon Polarimeters:

The fast polarimetry in RHIC is based on very small angle polarized proton-carbon (pC) elastic scattering in the Coulomb-Nuclear Interference (CNI) region. Typically 50-100 million events are collected in 30 seconds, giving a 3-4% relative uncertainty measurement of the beam polarization. Zero dead time readout is based on CAMAC waveform digitizers (WFD) developed at Yale University. The pC polarimeters provide the polarization normalization for the experiments for each fill. Measurements on the acceleration ramp are used to look for any polarization loss, particularly during studies of acceleration to 255 GeV. The main activity in late 2015, following operation during the pp and pA RHIC runs, was initial analysis of this polarimeter data, and further development of the analysis and studies of systematic effects. Major improvements implemented were:

- Simulations of electromagnetic fields in the scattering chamber indicated strong fields around the target-holder attachment points. Small metallic disks were placed around these sharp edges on targets where there was space in the scattering chamber.
- Adequate target lifetime requires thicker targets than the smallest that can be fabricated. These thicker targets introduce significant energy loss by the scattered carbon nuclei en route to the detectors, shifting the energy range measured and altering the asymmetry-polarization relationship. To monitor this effect, detectors in each pC polarimeter were reoriented to provide, through multiple scattering, sensitivity to the amount of target material traversed by scattered nuclei. The reoriented detectors also provide a measure of the mechanical stability of the carbon fiber targets, which may lend insight into their limited lifetimes.
- Scintillator-PMT pairs were installed on all four pC polarimeters, allowing the detection of prompt particles from beam-target interactions. Such prompts can provide a normalization of the interaction rate independent of many systematic effects in the detection of carbon nuclei in the silicon detectors. They also provide a measure of the beam time structure, which can be used in implementation a time-based calibration of the silicon detectors, and provide information useful for a longitudinal polarization profile measurement.

The results so far from studies of these improvements are:

- The targets with metallic disks had notably longer lifetime. This feature will be implemented for all future polarimeter operation.
- The data from the reoriented detectors in the 2015 pp and pA runs showed the expected relation between target material traversed and the measured asymmetry. However, the limited statistics provided by the DAQ system meant that a correction for this effect was negligible compared to the statistical uncertainty, and it was not implemented for the 2015 polarimetry measurements. However, this study will be of great use to a future upgraded polarimetry system, and will be described in a technical note.
- The event rate from the scintillator-PMT pairs provided an alternate measure of the polarization profile, for which the interaction rate is one component of the measurement. This alternate is being compared to using the rate from the detection of carbon nuclei in the silicon detectors, which has many systematic effects. A best measure and overall systematic uncertainties of the profile measurement is under study.

Activity in 2016 includes finalization of the 2015 polarization measurements, providing the RHIC experiments with precise polarization results and improved estimates of the systematic uncertainties of the measurements. Improvements to the measurement developed in recent years are incorporated, including:

- The detector gain instabilities were corrected for using the observed correlation between detector bias leakage current (frequently monitored throughout a RHIC fill) and alpha source gains (measured once per fill).
- The measured tilt of the spin vector from vertical was used to correct the H-jet measurements, where only the vertical component of spin is measured. This effect was negligible for the 100 GeV proton beams in 2015.

Further improvements are under investigation, including:

- A timing based method of calibration has been developed and allows self-calibration of each polarimeter measurement. Crosschecks of the accuracy of the method are being conducted. If these tests show precision greater than the gain variations within fills, the timing based method will be used for all 2015 polarization measurements.
- The longitudinal polarization profile is one of the most challenging polarimetry measurements. An approach using the beam time structure is under consideration.

Finally, preparations for the important 2017 p+p run are under way.

Hydrogen Jet Polarimeter:

The hydrogen jet polarimeter uses a polarized hydrogen target to provide the absolute polarization scale, with relative asymmetries for target and beam polarizations used to determine the beam polarization. The measurements are limited statistically by the diffuse nature of the jet target. These measurements are then used to normalize the scale of the pC polarimeters.

For the RHIC run in 2015, new silicon detectors were installed and new VME based readout electronics were commissioned for the second half of the run. The improved setup and the size of the recorded data set have enabled many systematic studies of the beam polarization for the first time. In addition to the energy calibration, which is carried out a few times each week, the proper identification of elastic events has been extended with an offline procedure for detector alignment with respect to the beam direction. The alignment complements a compensating magnetic field for the definition of the polarization direction in the target. In particular, in proton-heavy ion collisions, the offline alignment was important because of the large crossing angles of the beams at the location of the polarimeters that are a result of the accelerator rigidity for these asymmetric collision systems.

A newly developed interactive application with a graphical user interface provides fast feedback to the collider operation. The beam polarization is determined from fully background corrected beam and target asymmetries with cross checks between particle bunches of different colliding conditions (i.e. bunches that cross each other at just one or both experiments). Asymmetries are calculated as function of recoil proton energy. The new silicon detectors provide extended coverage compared to previous years and punch through particles can be identified from detector response and are subsequently removed. Detailed background studies of filled and unfilled RHIC bunches (also as function of recoil energy) make previous assumptions about polarization dependent inelastic production of particles unnecessary at this point. This provides the most accurate determination of the analyzing power in elastic proton proton scattering as function of momentum transfer at high energies ($\sqrt{s}$=13.8 GeV) to date. The remaining systematic uncertainty is dominated by the molecular fraction of the hydrogen in the jet target.

The 2015 data from the hydrogen jet polarimeter has also been used to measure the polarized longitudinal bunch structure for the first time. While no significant polarization reduction has been observed on the tails (compared to the transverse polarization profile), this result has served as important input to the discussion of possible options for luminosity leveling in the upcoming RHIC run in 2017.

<u>Contribution to EIC:</u>

Members of the group are active in many aspects of developing the EIC physics case as well as the design of the eRHIC detectors and interaction region. Significant effort was spent on detector and interaction region modeling, physics process simulation, and software tool development in order to demonstrate the future impact an EIC will have on our knowledge of proton and nuclear structure, and on the fundamental properties of QCD. Members of the group are in regular communication with the Collider-Accelerator Department (C-AD) at BNL, who are charged with the design of the eRHIC machine, to ensure all aspects of the physics program can be realized by the collider design. In the following section, the different activities of group members to the eRHIC effort are described.

Richard Petti has continued to support the science goals of the eRHIC project through design work and simulation of detectors within the interaction region of the accelerator. Richard has augmented the tools included in the simulation package, EicRoot, to support the required studies. Specifically Richard has recently worked with the machine group to develop a common interface for information exchange regarding the machine lattice layout and associated magnetic fields. He augmented the simulation code package to accommodate this new format, which has already proven to be extremely useful in allowing simulations with multiple design options to progress quickly. Richard has done significant development work into the design and placement of a luminosity monitoring system, implementing a feasible design into the simulation environment, as well as studying how beam optics and conditions can affect the luminosity measurement. Richard updated the "low Q2-tagger" design and has shown through simulation, that the acceptance coverage of such a detector is sufficient for the physics measurement needs. Richard has also studied the acceptance for forward going scattered protons in roman pot detectors placed at various locations within the specific machine lattice design. Recommendations have been made to the machine design group, which have been incorporated into a new interaction region design with very promising results. This allowed detailed comparisons of the roman pot acceptance for three different designs, which is extremely useful feedback for the machine design group. Richard has begun to lay the ground work for the simulations of the electron polarimetry system, communicating with the machine design group to find a suitable location within the ring for such a system, as well as writing code to simulate and generate Compton scattering events that are needed for the study. All of this progress has been presented to the EIC Generic Detector R&D Advisory Committee, who was pleased with the progress to date. Richard has implemented a reasonable setup within the simulation and has investigated analysis methods for extracting the electron beam polarization. Richard is also in the process of developing a different analysis technique using a finely segmented calorimeter and a 2-dimensional fitting procedure.

Alexander Kiselev continued to develop the full eRHIC detector GEANT simulation code (EicRoot) in the FairRoot software framework. In particular more justified TPC digitization parameters were chosen and tracker momentum resolution studies repeated in a configuration with the optimized solenoid magnetic field (see below). Physics simulations with the realistic track reconstruction procedure aimed to confirm the preliminary conclusions on degree of scattered electron $\{x,Q^2\}$ kinematic parameter smearing were performed and reported to the DIS 2016 physics conference recently. The conclusion of the study is that the foreseen tracker configuration will allow good $\{x,Q^2\}$ DIS parameter reconstruction using scattered electron track only, except for the kinematic area $y<0.1$ which can be partly recovered by using the response of the high resolution electromagnetic calorimeter at the very backward pseudorapidities. It was also shown, that significant fraction of the high Q^2 range can be gained back if the hadronic final state track information (the so called double-angle method) used in the reconstruction.

A much more realistic solenoid magnet configuration was designed, using Open Source software tools (Netgen, Elmer) with the subsequent verification by C-AD experts in the OPERA environment. With a relatively simple coil configuration it allows to have a sufficiently homogeneous field in the TPC volume and hadron-track-aligned magnetic field in the gas radiator RICH in the forward direction at the same time. First estimates, also reported to the recent DIS 2016 conference, show that the anticipated configuration should not disturb both aerogel proximity RICH performance in the whole pseudorapidity range as well as the CF_4 RICH operation in the hadron-going direction, where additional Cerenkov angle spread due to the track bending in the magnetic field does not exceed ~1 mrad for 10 GeV/c particles. Further studies in GEANT are foreseen.

Alexander Kiselev participated in the very successful calorimeter R&D test run at FNAL in spring 2016, where an improved version of the sampling electromagnetic calorimeter with the low-density tungsten-powder-based absorber and square scintillating fibers was tried out. It was experimentally demonstrated, that such a calorimeter being equipped with a PMT-based readout provides energy resolution of an order of $7\%/\sqrt{E}$ which is perfectly consistent with the results of GEANT simulation and is believed to be sufficient for almost the whole pseudorapidity range of the dedicated eRHIC detector. It is anticipated, that further R&D will be focused on simulation and manufacturing of a similar calorimeter with a compact SiPM-based readout.

Inspired by long-standing difficulties with the so-called zigzag GEM prototypes data analysis from the 2013 test run at FNAL, namely strong nonlinearities in response and regions with poor spatial resolution in general, Alexander also developed a custom simulation environment which allowed to optimize the “ideal” readout board design. He demonstrated, that detector performance could be improved a lot by careful tuning of expected charge sharing between neighboring strips at the board design stage. The results of this study were reported to the EIC Tracking R&D community and were highly appreciated. More detailed studies using realistic model of the electron cloud drift in the GEM detector electric fields have just started.

A related study with the aim to optimize the CF_4 RICH GEM readout plane pads was performed. It was shown, that even with the very small transverse size of the electron cloud (~130 microns) the readout pad layout can be improved a lot in a way to always have sufficient charge sharing between neighboring pads and gain therefore almost a factor of 2 in ring radius resolution, which is critically important to improve Cerenkov angle measurement.

Alexander Kiselev developed a standalone R&D version of the track finder and fitter code for the STAR forward upgrade configuration. It was demonstrated, that a reasonable configuration of 6 silicon disks with the small pixel size allows for a high efficiency track finding for events with up to a few hundred charged tracks in the pseudorapidity range [2.5 .. 4.0]. Full reconstruction of central collision Au-Au events with a few thousand tracks in this pseudorapidity range can however still be a challenge. It was also shown, that even in the weak 0.5T field of the STAR solenoid magnet one can expect sufficiently good momentum resolution of an order of ~20% or better at pseudorapidity ~2.5 for the P_t range of interest. Higher pseudorapidities (up to the anticipated ~4.0) may however be problematic for momentum reconstruction because of the vanishing Bdl integral at small angles.

Brian Page continued his investigations into the utility of jet and di-jet observables at an eRHIC. In addition to determining optimal jet algorithm parameters, early work demonstrated the feasibility of tagging quark and gluon initiated jets using several jet properties in conjunction with multivariate analysis techniques. Current work is focused on using di-jets, as a complement to g_1 measurements, to probe the gluon contribution to the spin of the proton. It is hoped that the hard scale provided by the di-jet mass will also allow for the extension of measurements below a Q^2 of 1 GeV^2.

Work has also begun on implementing a diffractive event Monte Carlo for the purpose of exploring the sensitivity of an eRHIC to a number of di-jet angular correlations which are the subject of recent theoretical investigation and which may be sensitive to gluon saturation effects as well as the gluon Wigner distribution.

Xiaoxuan Chu is working on the photon structure at EIC under the supervision of E.C. Aschenauer. In ep collision, the interaction of electrons and protons at low virtuality is dominated by photo-production process with electrons scattering at small angles. At EIC, the resolved and direct processes can be well separated. She has reconstructed x_γ by tagging di-jets produced in resolved processes based on the existing Monte Carlo framework. The unpolarized photon PDFs can be extracted by measuring the di-jets cross section. In the next step, she will continue working the polarized photon PDFs, which is a critical input for $\gamma\gamma$ ILC option.

Salvatore Fazio finalized the eRHIC potential in measuring exclusive processes in e-p collisions. Such measurements, together with DVCS and heavy mesons will provide insight into both the transverse distribution of quarks and gluons, and the decomposition of the proton spin. Salvatore also started to investigate the eRHIC potential in measuring the nuclear structure-function and the impact on extracting the nuclear parton distribution functions. Preliminary results indicate that eRHIC data will lead to a significant reduction in the uncertainties of gluon and quark distributions.

Salvatore Fazio also served as a convener for the EIC User's Group Meeting held on July 7-9, 2016 at Argonne National Laboratory.

Elke Aschenauer and J.H. Lee in collaboration with Liang Zheng and Bowen Xiao at CCNU have been ways to measure the Gluon Sivers Function at an EIC.

Studying the largely unexplored gluon Sivers function (GSF) is important to obtain a complete picture of the 2d+1 momentum structure of the proton. It has been proposed that the GSF can be studied through the dihadron single spin asymmetry (SSA) with the future high energy, high luminosity Electron-Ion Collider (EIC). We started a detailed study on the feasibility of measuring the dihedron SSA arising from the GSF with the back-to-back charged hadrons, K+K- and DDbar pair. It has been shown that DDbar pair is a clean probe for the study while measuring it will be statistically challenging. We've explored feasibilities of measuring the GSF with other gluon probing channels - unidentified dihedron correlations and also with K+K- pair.

Elke Aschenauer and JH Lee in collaboration with M.D. Baker are working on refining the detector requirements for eA Collisions in the Nuclear Shadowing/Saturation Regime. It has been propose to upgrade the eA DIS event generator DPMJetHybrid (developed by EA, JHL, and Liang Zheng) to include some key nuclear shadowing / parton saturation effects that are currently missing in the suite of eA event generators available for physics simulations. These event generators have been essential in establishing detector requirements for various physics measurements. However, the particle production model in the forward region for eA needs improvement in order to clarify those requirements for measurements at an EIC. We have started adding flexibility of the eA generator by tuning and adding intrinsic k_T and multi-nucleon k_T-recoil sharing for eA collisions. This model will automatically factor in improved information as we include updated nuclear PDFs from RHIC or the LHC. In order to test and tune the model, we plan to use it to study the impact of forward detectors on two important topics in eA: centrality measures and correlations between forward particles and particles from the hard scattering, extending the study performed by EA, JHL, and Liang Zheng.

Summary of Talks and Conference/Workshop Organization:
Period: October 1st 2015 – June 30th 2016

Name	Talks (Invited)	Conferences /Workshops organized
Lab Permanent Staff		
E.C. Aschenauer	12 (10)	1
A. Bazilevsky	2 (2)	
W. Guryn	4 (3)	
A. Ogawa	1 (1)	
J.H. Lee	2 (2)	
W. Schmidke	1	
Term and Other Staff		
O. Eyser	3 (3)	
A. Kiselev	3 (2)	
S. Fazio	3 (2)	1
Post-docs		
P. Page	3 (2)	
R. Petti	1 (1)	1
G. Webb	1 (1)	
PhD Students		
X. Chu	3 (2)	
D. Kalinkin	/	
Total	**39**	**3**

Bibliography:
The papers listed here are only the publications of PHENIX and STAR related to the polarized p+p program. All group members are also authors of the papers related to heavy ion collisions at RHIC, which are not listed here.

RHIC SPIN :

1. The RHIC Cold QCD Plan for 2017 to 2023: A Portal to the EIC
   E.C. Aschenauer et. al., arXiv:1602.03922

PHENIX :

1. Measurements of double-helicity asymmetries in inclusive J/\Ψ production in longitudinally polarized p+p collisions at $\sqrt{s}$=510 GeV; arXiv:1606.01815 [hep-ex], submitted to Phys. Rev. D
2. Measurement of parity-violating spin asymmetries in $W^{\pm}$ production at midrapidity in longitudinally polarized p+p collisions. arXiv:1504.07451, Phys.Rev. D 93, 051103(R) (2016).
3. Inclusive cross section and double helicity asymmetry for p0 production at mid-rapidity in p + p collisions at $\sqrt{s}$=510 GeV, PHENIX Collaboration; arXiv:1510.02317 [hep-ex], Phys.Rev. D 93, 011501(R) (2016).

STAR:

1. Measurement of the transverse single-spin asymmetry in $p^{\uparrow}+p \rightarrow W^{\pm}/Z^{0}$ at RHIC.
   Phys. Rev. Lett. 116 (2016) 132301

2. Observation of Transverse Spin-Dependent Azimuthal Correlations of Charged Pion Pairs in $p^{\uparrow}+p$ Collisions at $\sqrt{s}$=200 GeV. Phys. Rev. Lett. 115 (2015) 242501

EIC/eRHIC:

1. Unveiling the Proton Spin Decomposition at a Future Electron-Ion Collider. Elke C. Aschenauer, R. Sassot, M. Stratmann; arXiv:1509.06489 [hep-ph], Phys.Rev. D92 (2015) no.9, 094030.

Non-RHIC/EIC related Publications with contributions by one of the group members:

Elke-Caroline Aschenauer:

1. Reply Comments on Phys. Rev. D89, 097101 (2014) "Reevaluation of the parton distribution of strange quarks in the nucleon", E.C. Aschenauer et al, Phys. Rev. D 92, 098102
2. TMDs and SSAs in hadronic interactions
   E.C. Aschenauer, U. D'Alesio and F. Murgia, Eur.Phys.J. A52 (2016) no.6, 156

Alexander Kiselev:

1. A Study of a Mini-drift GEM Tracking Detector. B. Azmoun, B. DiRuzza, A. Franz, A. Kiselev, R. Pak, M. Phipps, M.L. Purschke, C. Woody; arXiv:1510.01747 [physics.ins-det], submitted to Trans. Nucl. Sci.
2. The structure effects in polarization and cross section in inelastic A(p,p')X reaction with 40Ca and 12C nuclei at 1GeV. O. Miklukho, A. Kisselev et al, arXiv:1606.03006 [nucl-ex], submitted to Physics of Atomic Nuclei (russian)

William Schmidke:

1. H1 and ZEUS Collaboration
   Combination of differential D*+/- cross-section measurements in deep-inelastic ep scattering at HERA
   H. Abramowicz et al., JHEP 1509 (2015) 149.

2. ZEUS Collaboration
   Production of exclusive dijets in diffractive deep inelastic scattering at HERA
   H. Abramowicz et al., Eur.Phys.J. C76 (2016) no.1, 16.

3. H1 and ZEUS Collaborations
   Combination of measurements of inclusive deep inelastic e+/-p scattering cross sections and QCD analysis of HERA data
   H. Abramowicz et al., Eur.Phys.J. C75 (2015) no.12, 580.

GRADUATE STUDENT AND POST-DOC TRACKING INFORMATION

TABLE 2a: TRACKING INFORMATION for Resident Graduate Students stationed for more than 3 months (October 2015 – June 2016)

Grad. Student Name	Registered University	University Advisor	Lab Staff co-advisor	Degree awarded / expected (MS/PhD)
Dmitry Kalinkin	Indiana University	Prof. Scott Wissink	E.C. Aschenauer	2019
Xiaoxuan Chu	Central China Normal University	Prof. Xu Cai	E.C. Aschenauer	2018
Zhanwen Zhu	Shandong University	Prof. Qinghua Xu	E.C. Aschenauer	2017

TABLE 2b: TRACKING INFORMATION for Resident Undergraduate Students working for more than 3 months in the reporting period at BNL (October 2015 – June 2016)

Undergraduate Student	Advisor	Beginning Date	End Date	Present Institution	Present/Future Position

FY2015 U.S. Department of Energy

Budget Page

ORGANIZATION					Budget Page No.: 1
Brookhaven National Laboratory **Medium Energy**					
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR					Requested Duration: 12 (months)
Elke Aschenauer					
A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates (List each separately with title; A.6. Show number in brackets)	DOE Funded Person-mos.				
1. Elke Aschenauer Physicist	12.0				
2. Alexander Bazilevsky Physicist	8.5				
3 Kjeldoleg Eyser Assoc Physicist	12.0				
4 Wlodzimierz Guryn Physicist	7.8				
5 Akio Ogawa Physicist	11.5				
6 William Schmidke Jr. Physicist	9.1				
7 Jeonghun Lee Physicist	3.2				
Others (List individually on Budget Explanation Page)					
7 Total Senior Personnel	64.2	0.0	0.0	$1,086,225	
B. OTHER PERSONNEL (show numbers in brackets)	M.m(months)				
1. 1 Post Doctoral Associates	10.8			$73,681	
2. Other Professional					
3. Graduate Students					
4. ( ) Undergraduate Students					
5. 1 Secretarial - Clerical	6.4			$37,167	
6. Others (List individually on Budget Explanation Page) (joint appointment)					
Total Salaries and Wages (A + B)				$1,197,073	
C. Fringe Benefits (if charged as Direct Costs) Included in salary band rate				$0	
Total Salaries,Wages and Fringe Benefits (A + B + C)				$1,197,073	
D.					
Total Permanent Equipment					
E. Travel 1. Domestic (incl. Canada and U.S. Possessions)				$20,876	
2. Foreign				$20,224	
Total Travel				$41,100	
F. Trainee/Participant Costs					
1. Stipends (Itemize levels, types and totals on budget justification page)					
2. Tuition & Fees					
3. Trainee Travel					
4. Other (fully explain on justification page)					
Total Participants Total Cost				$0	
G. Other Direct Costs					
1. Materials and Supplies				$16,625	
2. Publication Costs/Documentation/Dissemination					
3. Consultant Services					
4. Computer (ADPE) Services					
5. Subcontracts				$32,155	
6. Other Organizational Burden, Space, electric, communications, other)				$311,029	
Total Other Direct Costs				$359,809	
H. **Total Direct Costs (A through G)**				$1,597,982	
I. Indirect Costs (specify rate and base)					
Total Indirect Costs				$664,434	
J. **Total Direct and Indirect Costs (H + I)**				$2,262,416	
K. Amount of any Required cost sharing from Non-federal Sources					
L. **Total Cost of Project (J + K)**				$2,262,416	

FY2016 U.S. Department of Energy

Budget Page

ORGANIZATION				Budget Page No.: 1
Brookhaven National Laboratory **Medium Energy**				
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR				Requested Duration: 12 (months)
Elke Aschenauer				
A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates (List each separately with title; A.6. Show number in brackets)	DOE Funded Person-mos.			
1 Elke Aschenauer Physicist	12.0			
2 Alexander Bazilevsky Physicist	9.0			
3 Kjeldoleg Eyser Assoc Physicist	12.0			
4 Wlodzimierz Guryn Physicist	9.0			
5 Akio Ogawa Physicist	12.0			
6 William Schmidke Physicist	9.0			
7 Jeonghun Lee Physicist	6.0			
Others (List individually on Budget Explanation Page)				
7 Total Senior Personnel	69.0	0.0	0.0	$1,167,455
B. OTHER PERSONNEL (show numbers in brackets)	M.m(months)			
1. 1 Post Doctoral Associates	10.8			$72,694
2. 1 Other Professional	0.7			$7,085
3. Graduate Students				
4. ( ) Undergraduate Students				
5. 1 Secretarial - Clerical	3.6			$24,902
6. Others (List individually on Budget Explanation Page) (joint appointment)				
Total Salaries and Wages (A + B)				$1,272,136
C. Fringe Benefits (if charged as Direct Costs) Included in salary band rate				$0
Total Salaries,Wages and Fringe Benefits (A + B + C)				$1,272,136
D.				
Total Permanent Equipment				
E. Travel 1. Domestic (incl. Canada and U.S. Possessions)				$24,000
2. Foreign				$21,000
Total Travel				$45,000
F. Trainee/Participant Costs 1. Stipends (Itemize levels, types and totals on budget justification page) 2. Tuition & Fees 3. Trainee Travel 4. Other (fully explain on justification page)				
Total Participants	Total Cost			$0
G. Other Direct Costs				
1. Materials and Supplies				$22,721
2. Publication Costs/Documentation/Dissemination				
3. Consultant Services				
4. Computer (ADPE) Services				
5. Subcontracts				$79,325
6. Other Organizational Burden, Space, electric, communications, other)				$356,588
Total Other Direct Costs				$458,634
H. **Total Direct Costs (A through G)**				$1,775,770
I. Indirect Costs (specify rate and base)				
Total Indirect Costs				$747,695
J. **Total Direct and Indirect Costs (H + I)**				$2,523,465
K. Amount of any Required cost sharing from Non-federal Sources				
L. **Total Cost of Project (J + K)**				$2,523,465

Budget Explanation

A. Senior Personnel Man/Montl Cost

Staff Listing is shown on the Budget Sheet.

B. Other Personnel

C. Fringe and labor burden which are included in the salary band rate

All fringe costs are included in the standard labor rates included in A and B sections. Salary cost data includes salary, paid absence, overtime shift and fringe benefit costs.

D. Capital Equipment

E. Travel

Includes attendance at conferences and visitors to BNL workshops

F. Trainee/Participant Costs

G. Other Direct Costs

Includes: Space, Physics Department Organizational burdens, On-site Housing and Miscellaneous Expenses

	FY 15 %	FY 16 %	
Organizational Burden	14.5	14.7	applied to salary with fringe
Electric Distributed	1.18	1.18	applied to salary with fringe

I. Indirect Costs

	FY 15 %	FY 16 %	
BNL Material Burden	7.50	7.50	applied to travel, purchases and subcontracts
BNL Common G&A	31.95	32.35	applied to , direct salary plus fringe, organizational burden, purchased goods, material burden, & allocated services
BNL Traditional G&A	8.25	8.25	applied to , direct salary plus fringe, organizational burden, purchased goods, and material burden
BNL LDRD Burden	3.70	2.30	In FY15 = applied to , direct salary plus fringe, organizational burden, purchased goods, material burden, & allocated services In FY16 = base is applied to Total Cost less housing
Composite rate	43.9	43.8	